



Characterization of Near Earth Asteroids

Workshop #2 with South Africa

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October 27, 2014



NEO Observations Program



US component to International Spaceguard Survey effort
Has provided 98% of new detections of NEOs since 1998

Began with NASA commitment to House Committee on Science
in May 1998 to find at least 90% of 1 km and larger NEOs

- Averaged ~\$4M/year Research funding 2002-2010
- That goal reached by end of 2010

NASA Authorization Act of 2005 provided additional direction:

“...plan, develop, and implement a Near-Earth Object Survey program to detect, track, catalogue, and characterize the physical characteristics of near-Earth objects equal to or greater than **140 meters** in diameter in order to assess the threat of such near-Earth objects to the Earth. It shall be the goal of the Survey program to achieve **90 percent completion** of its near-Earth object catalogue **within 15 years** [by 2020].

Updated Program Objective: Discover $\geq 90\%$ of NEOs larger than 140 meters in size as soon as possible

- Starting with FY2012, now has \$20.5 M/year
- FY2014 budget increases to \$40.5 M/year



Background



- US President's new plan for human space flight, announced April 15, 2010*, establishes the goal of conducting a human mission to an NEO by 2025

* <http://www.whitehouse.gov/the-press-office/remarks-president-space-exploration-21st-century>

- US National Space Policy, June 28, 2010*

NASA shall: "Pursue capabilities, in cooperation with other departments, agencies, and commercial partners, to detect, track, catalog, and characterize near-Earth objects to reduce the risk of harm to humans from an unexpected impact on our planet and to identify potentially resource-rich planetary objects."

* http://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf

- US President's FY2014 NASA Budget Request:

"The budget request includes a doubling of NASA's efforts to identify and characterize potentially hazardous near-Earth objects (NEOs). This increase in the budget reflects the serious approach NASA is taking to understand the risks of asteroid impacts to our home planet. It will also help identify potential targets for the future human mission to an asteroid."



NASA's NEO Search Program

(Current Systems)



Minor Planet Center (MPC)

- IAU sanctioned
- Int'l observation database
- Initial orbit determination

<http://minorplanetcenter.net/>

NEO Program Office @ JPL

- Program coordination
- Precision orbit determination
- Automated SENTRY

<http://neo.jpl.nasa.gov/>



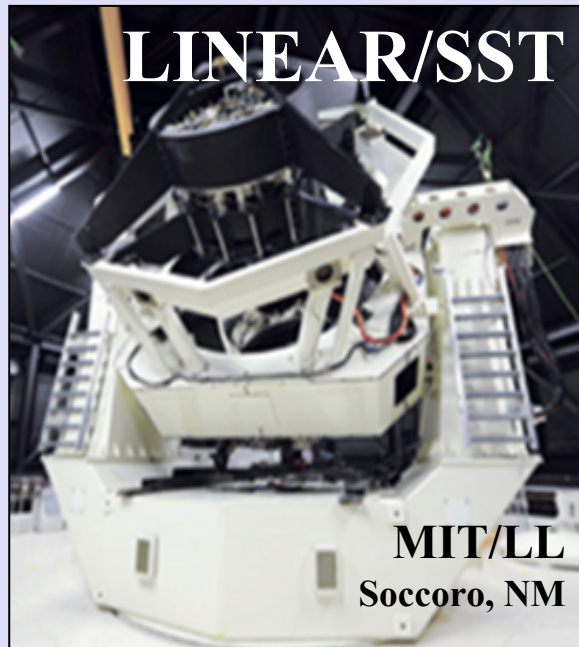
NEO-WISE

JPL
Sun-synch LEO

Operations
Jan 2010
Feb 2011,
129 NEAs found

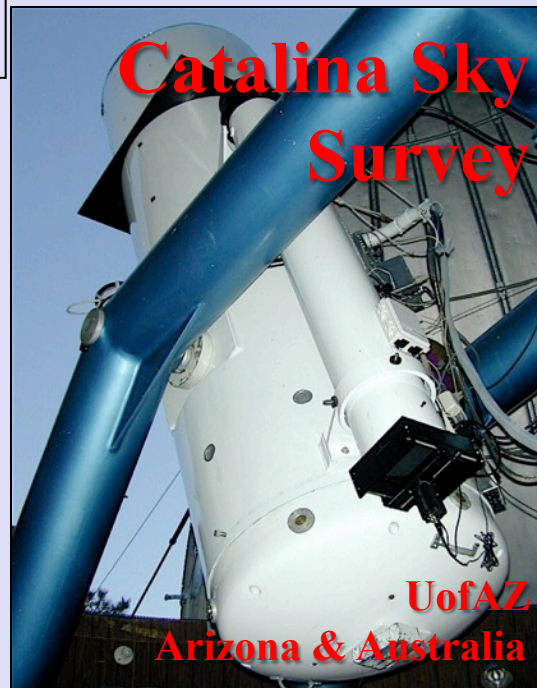
Reactivated
Sep 2013

Ops in Dec
6 NEAs 1 comet



LINEAR/SST

MIT/LL
Socorro, NM



Catalina Sky Survey

UofAZ
Arizona & Australia



Pan-STARRS

Uof HI
Haleakula, Maui



Data Analysis/Management

- Minor Planet Center (MPC)
 - Smithsonian Astrophysical Observatory, Cambridge, MA
 - Dr Tim Spahr, Director
 - Worldwide observation coordination and correlation, initial orbit determination

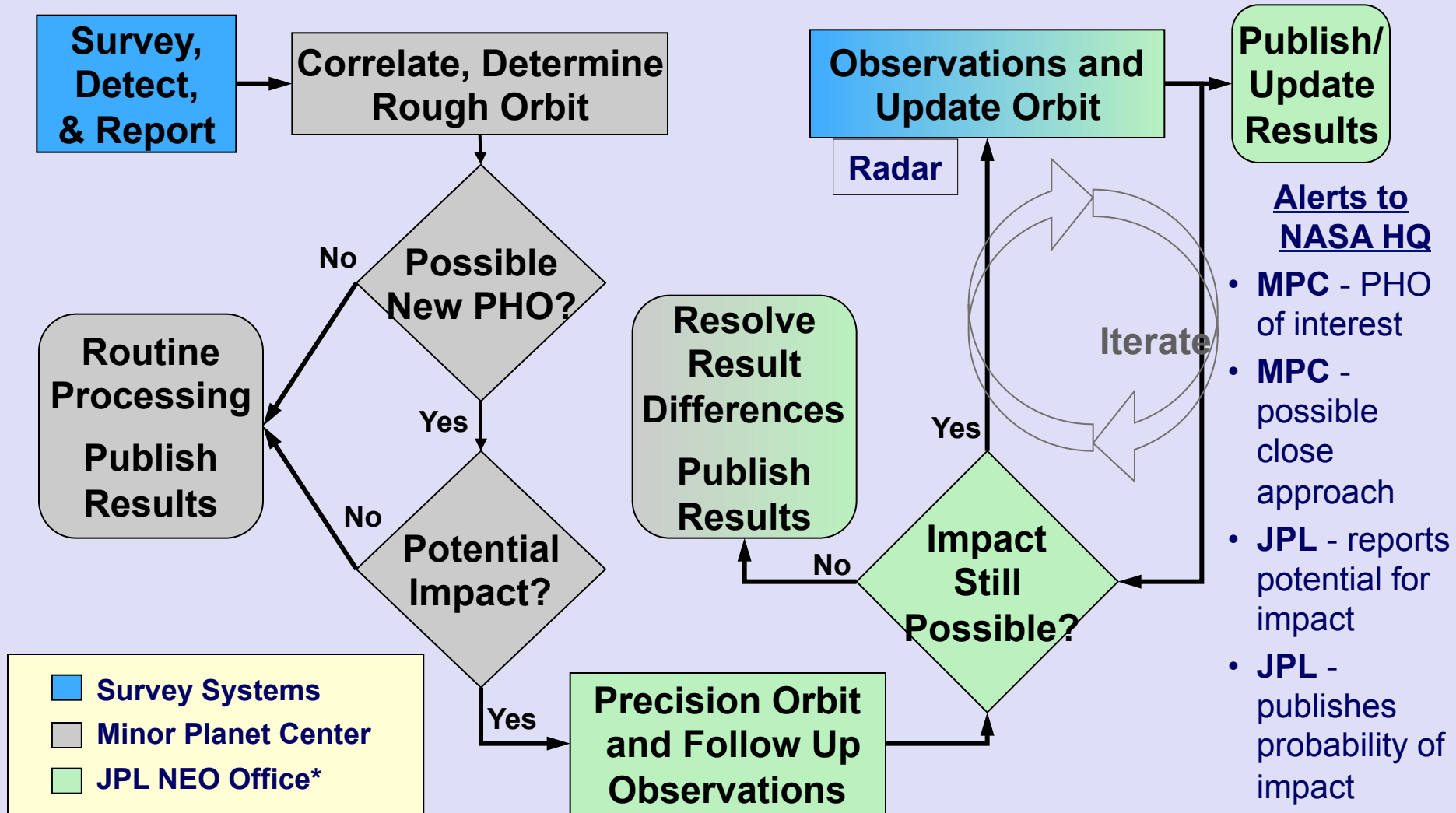
<http://minorplanetcenter.net/>
- Near Earth Object Program Office
 - Jet Propulsion Laboratory, Pasadena, CA
 - Dr Donald Yeomans, Program Manager
 - Precision orbit determination and hazard prediction
 - Compares results with NEODynamics System, Univ of Pisa, Italy

<http://neo.jpl.nasa.gov>



Spaceguard Survey Catalog Program

Current Spaceguard Survey Infrastructure and Process



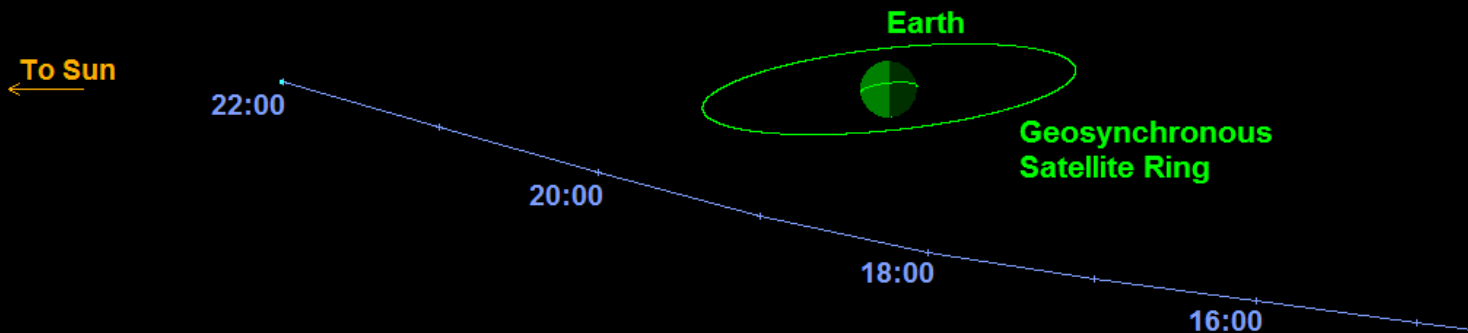
* In parallel with NEODyS



Near Earth Asteroid Close Approach



Asteroid 2014 RC: Close Approach to Earth, Sep. 7, 2014



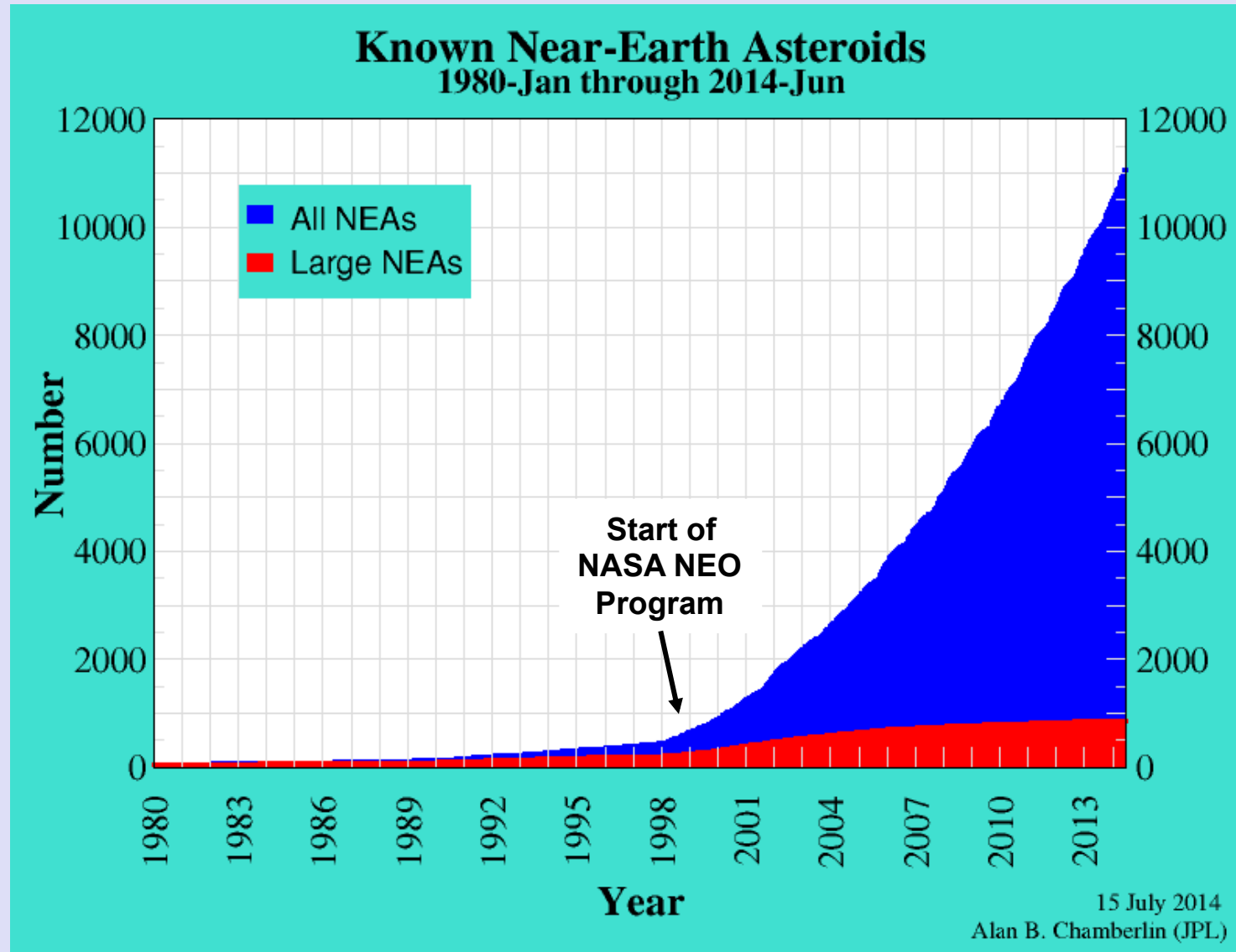
1 hour time ticks, times in UTC

100000 km

P. Chodas (NASA/JPL)



Known Near Earth Asteroid Population



11,542
10/01/14

Includes 94
comets

1505
PHAs

862
10/01/14

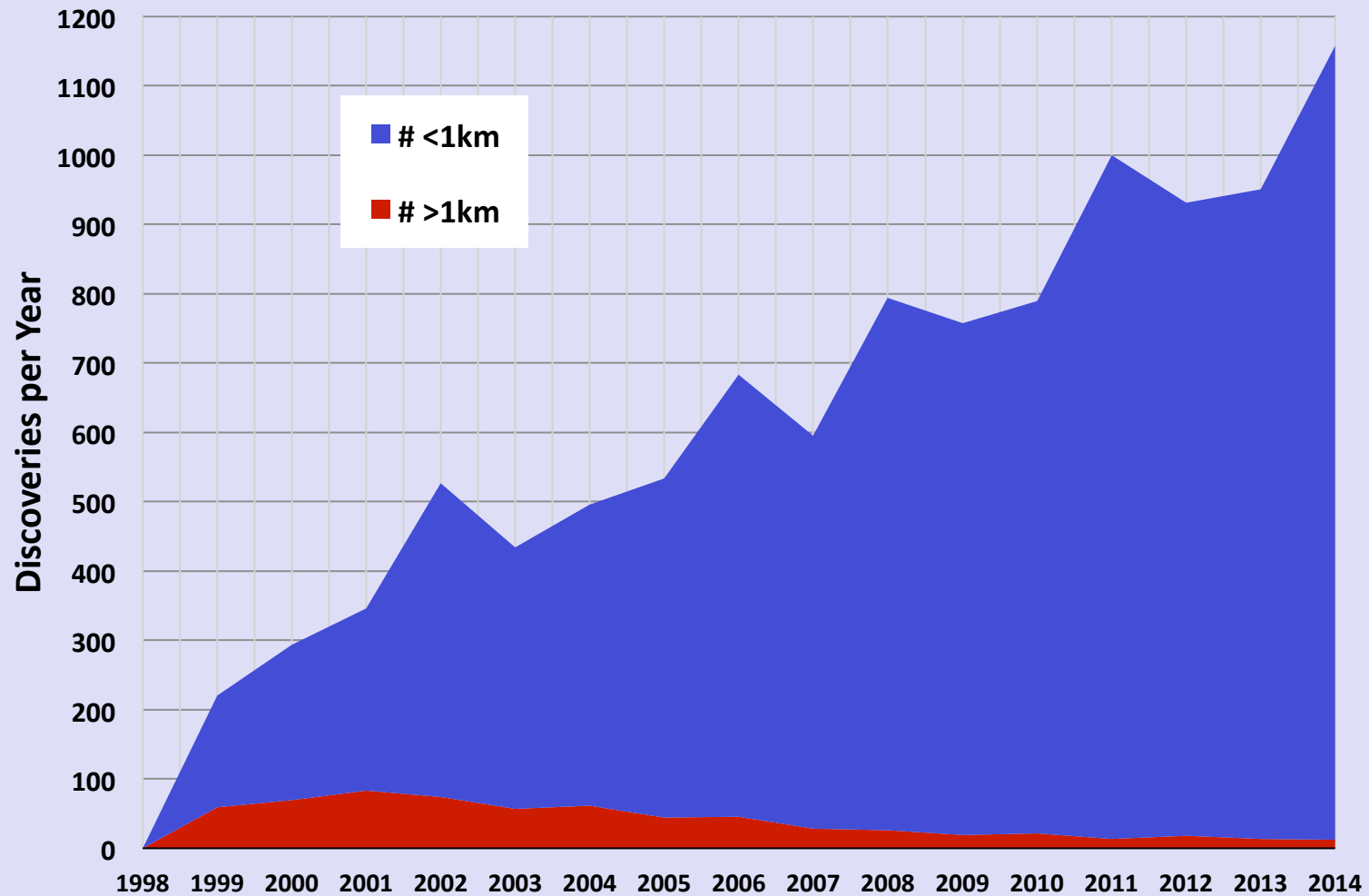
155 PHAs



Near Earth Asteroid Discoveries



NEA Discovery Stats



Physical Characterization of NEAs



- **Radar** is essential for obtaining an accurate estimate of size and shape to within ~2 m, as well as rotation state.
- Ground-based and space-based **IR** measurements are important for estimating albedo and spectral class, and from these an approximate density can be inferred.
- **Light curves** are important to estimate shape and rotation state.
- **Long-arc high-precision astrometry** is important for determining the area-to-mass ratio.
- Mass is estimated from size and shape using an inferred or assumed density, and it should be constrained by the estimate of the area-to-mass ratio. Even so, mass may only be known to within a factor of 3 or 4.
- Composition can only be roughly assessed via analogy to spectral class.

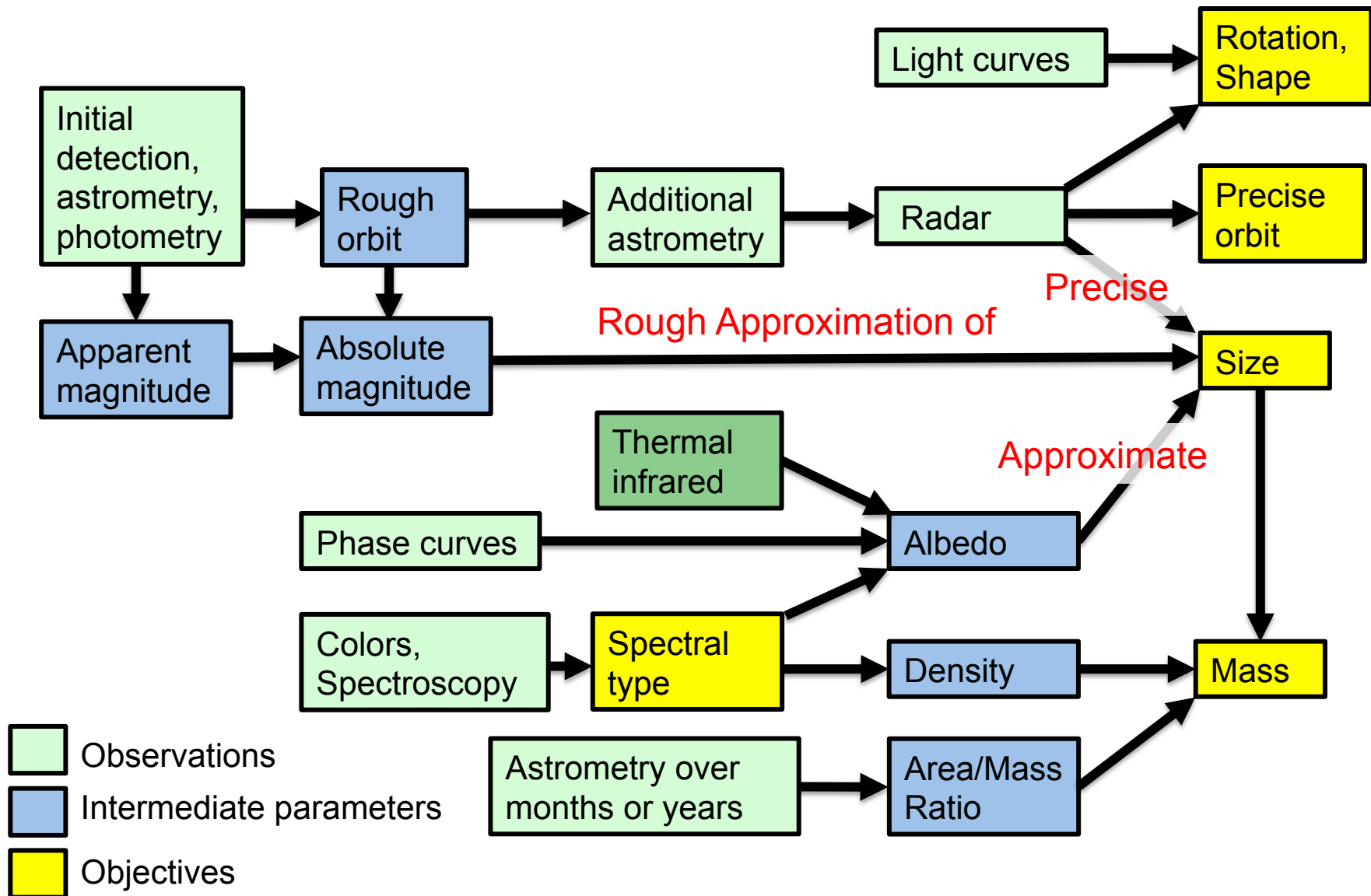


Assumed albedo
 $\rho = 0.04$



Assumed albedo
 $\rho = 0.34$

Characterization Process



NEO Infrared Characterization



NASA InfraRed Telescope Facility (IRTF)

- Dedicated Planetary Science Observatory
- Characterization of Comets and Asteroids
- Spectroscopy and Thermal Signatures
- On-call for Rapid Response on Discoveries

Spitzer Infrared Space Telescope

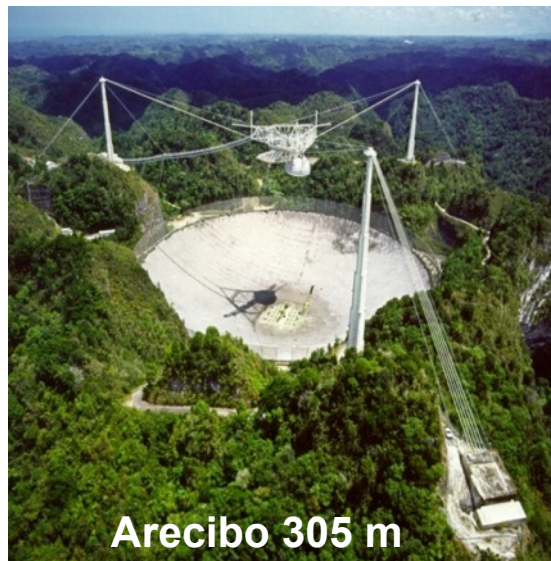
- Orbit about Sun, ~176 million km from Earth
- In extended Warm-phase mission
- Characterization of Comets and Asteroids
- Thermal Signatures, Albedo/Sizes of NEOs
- Longer time needed for scheduling



Radar Observations of NEOs



Goldstone 70 m

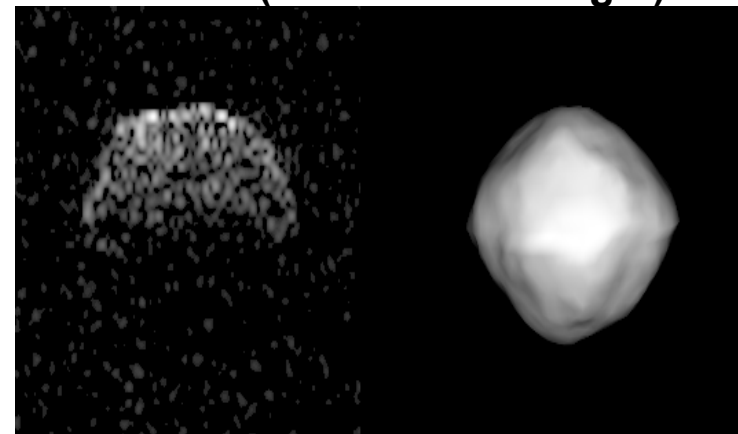


Arecibo 305 m



- These are complementary capabilities.
 - Arecibo has more power and range
 - Goldstone has more resolution and field of regard
- Currently, 70-80 NEOs are observed every year.
- Radar observations can provide:
 - Size and shape to within ~2 meters.
 - High precision range/Doppler orbit data.
 - Spin rate, surface density and roughness.

Bennu (OSIRIS-REx Target):

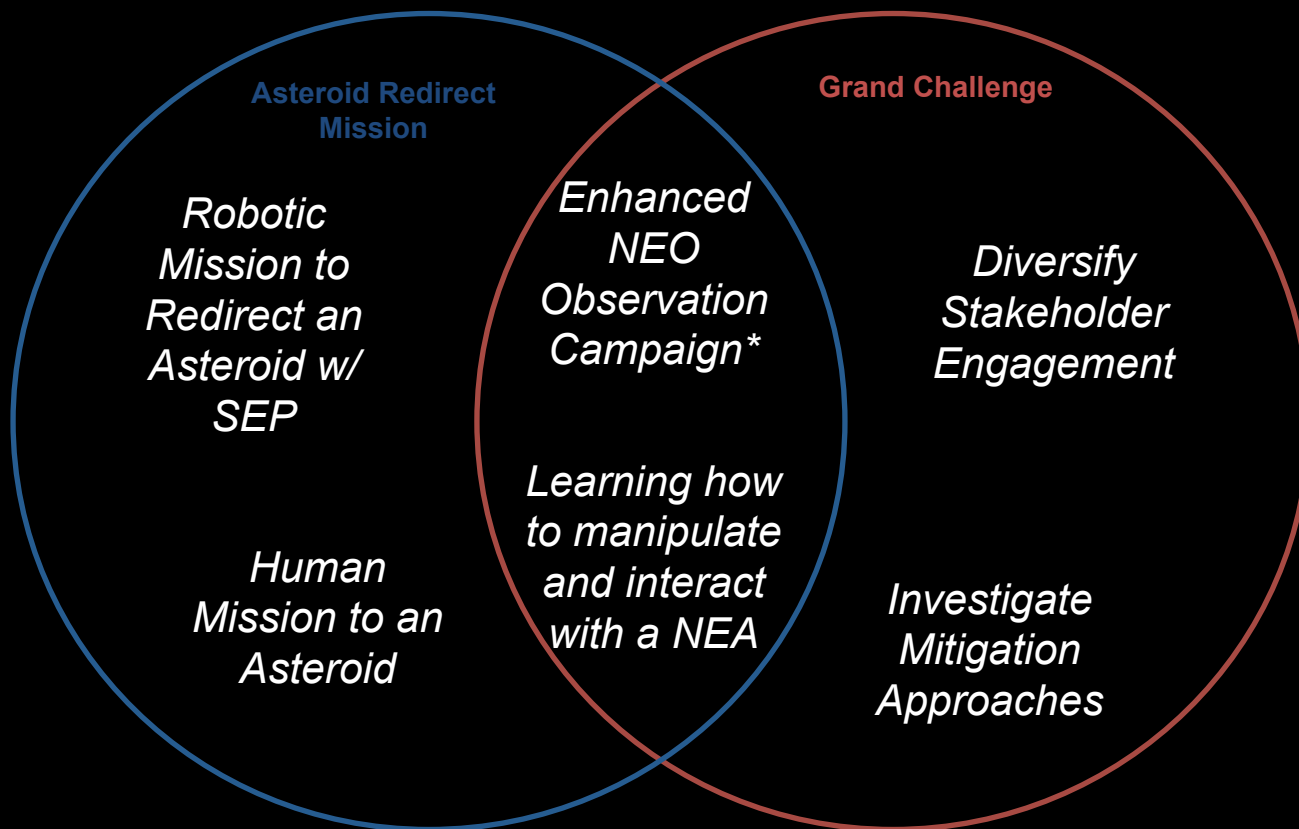


Observations

Shape Model

FY14 Asteroid Initiative: What and How

Asteroid Initiative



Both sets of activities leverage existing NASA work while amplifying participatory engagement to accomplish their individual objectives and synergize for a greater collective purpose.

* FY2014 Budget increases NEOO Program to \$40M/ year

Asteroid Redirect Mission: Three Main Segments



IDENTIFY

Ground and space based assets detect and characterize potential target asteroids



Pan-STARRS



NEOWISE

Goldstone

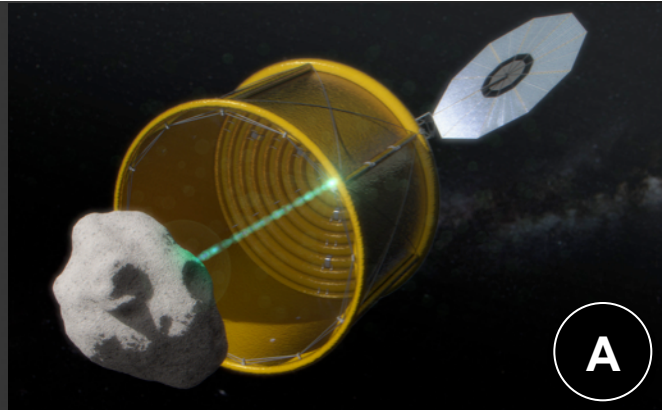
Arecibo



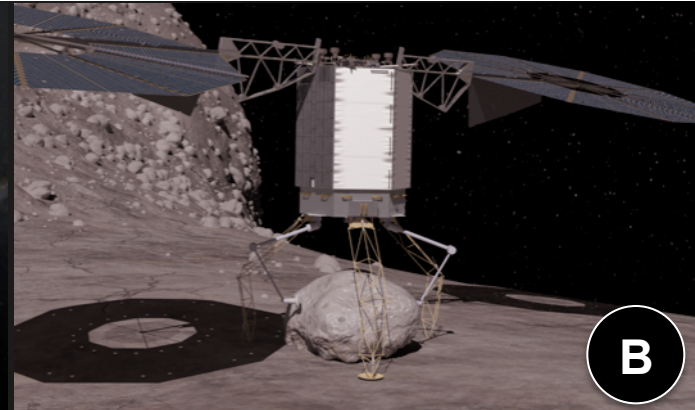
Infrared Telescope Facility

REDIRECT

Solar electric propulsion (SEP) based system redirects asteroid to cis-lunar space (two capture options)



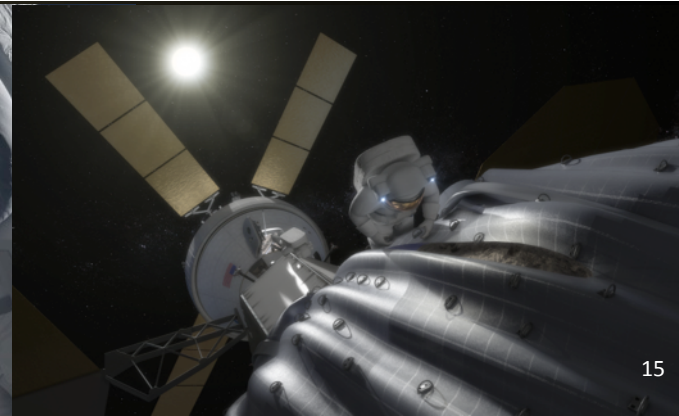
A



B

EXPLORE

Crews launches aboard SLS rocket, travels to redirected asteroid in Orion spacecraft to rendezvous with redirected asteroid, studies and returns samples to Earth

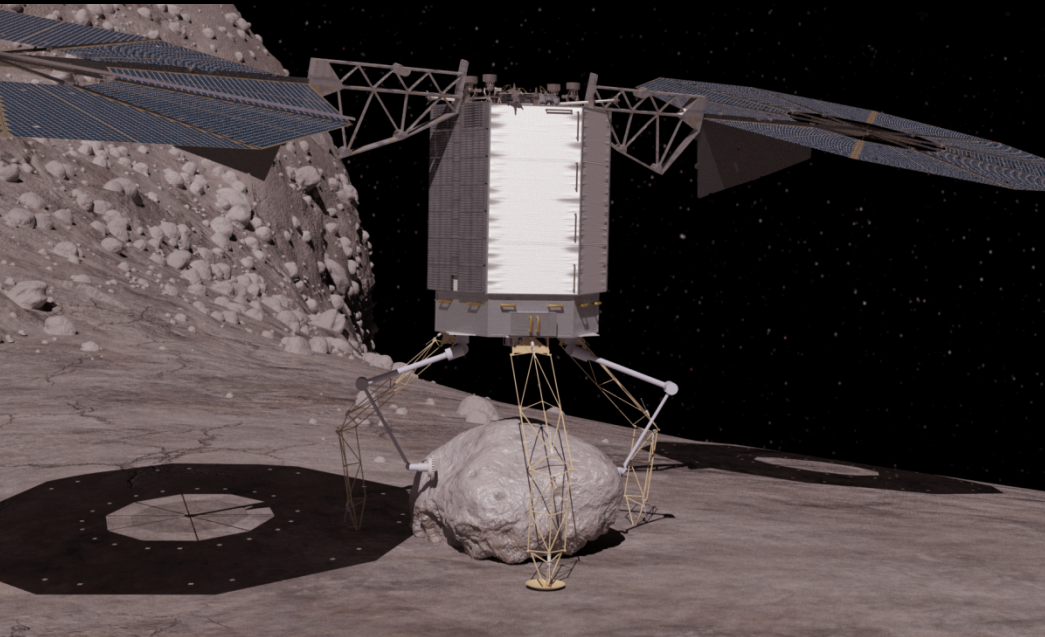
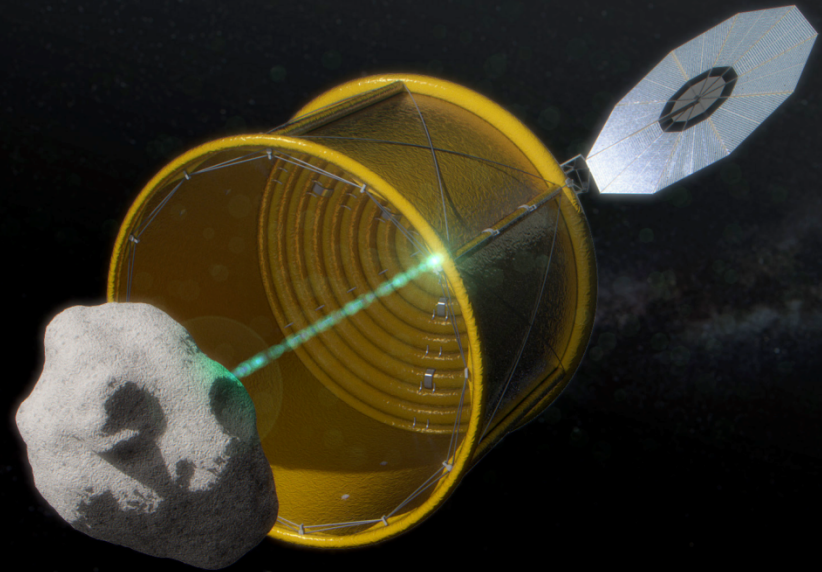


Asteroid Redirect Mission: Two Robotic Capture Options



Option A for “Asteroid”

- Rendezvous with a <10 m asteroid
- Demonstrate some basic planetary defense techniques
- Match its spin, capture it and despin
- Guide the asteroid back to lunar orbit
- Max asteroid mass depends on orbit, but is likely on the order of 100 tons



Option B for “Boulder”

- Rendezvous with a 100+ m asteroid
- Characterize its surface, select boulder
- Land on the asteroid and collect the boulder, probably ~2-4 m in size
- Demonstrate gravity tractor deflection
- Bring the boulder back to lunar orbit
- Max boulder mass depends on orbit, but is likely on the order of 10 tons

Candidate Targets for Option A



- To be a **potential candidate**, an asteroid must have:
 - An Earth-like orbit with $V_{infinity} < \sim 2.6$ km/s
 - A close approach to Earth in the early 2020s
 - An absolute magnitude in the range $\sim 30 < H < \sim 27$ (which corresponds to a size in the range of a few meters to a few tens of meters, depending on albedo)
- **So far, 9 known asteroids satisfy these constraints**
- Thousands of potential candidates must exist, but they are hard to detect
- Discovery rate of potential candidates: currently about **2-3 per year**, expected to increase to **~5 per year**
- To become a **valid candidate**, physical properties must be further constrained:
 - Mean size $< \sim 10$ m, max size $< \sim 13$ m
 - Rotation period $< \sim 2$ minutes
 - Mass likely to be less than maximum return mass for the orbit
- Rapid response after discovery is important for physical characterization:
 - Large-aperture optical telescopes: Rotation rate, colors, photometry, area-to-mass
 - Radar: Size to within ~ 2 m, rotation state, high-precision astrometry
 - Ground-based or space-based IR: Size, albedo, spectral class
- **3 asteroids have been characterized well enough to be considered valid candidates**

Candidate Targets for Option B



- To be a **potential candidate**, an asteroid must have:
 - An accessible orbit about the Sun (in particular, a low inclination orbit)
 - A size in the general range ~100 to 500 meters ($\sim 24 < H < \sim 19$)
- Lots of potential candidates are known (some more accessible than others)
- To become a **valid candidate**, however, there must be observational evidence of boulders on the asteroid's surface.
- **The surface of the asteroid must be characterized and the existence of boulders of the size which can be returned must at least be inferred**
- Two means of characterizing the surface:
 - 1) Spacecraft imaging from a **precursor mission**, or
 - 2) Ground-based **radar with high enough SNR to detect boulders**.
- 1 candidate has already been validated by a precursor mission (Itokawa), and 2 more should be, before 2019 (Bennu and 1999 JU3)
- 2 candidates have been validated by radar, and more should be, at a rate of ~1 per year

Currently Known Candidate Asteroids for ARM



- **For Option A:**

- Currently, 9 potential candidates; 3 found last year
- 3 **validated** candidates:
 - **2009 BD** – ~ 4 meter size inferred by Spitzer data
 - **2013 EC20** – ~ 2 meter size determined by radar imaging
 - **2011 MD** – ~ 6 meter size determined by Spitzer data
- Possibly another candidate validated in 2016: **2008 HU4** – radar opportunity
- Additional valid candidates expected at a rate of 1-2 per year

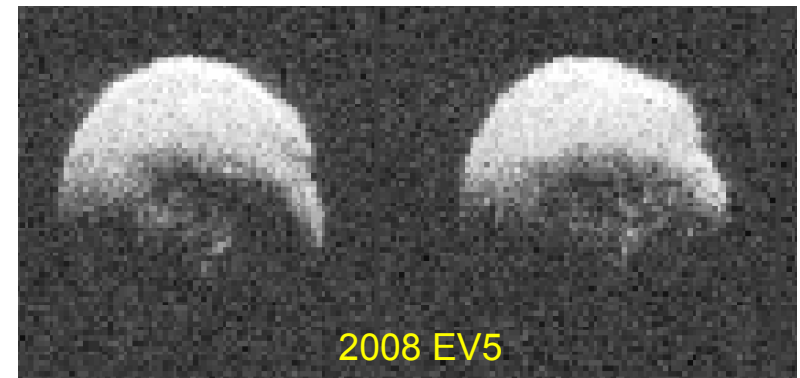
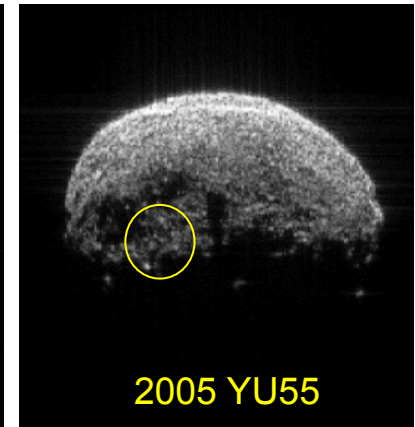
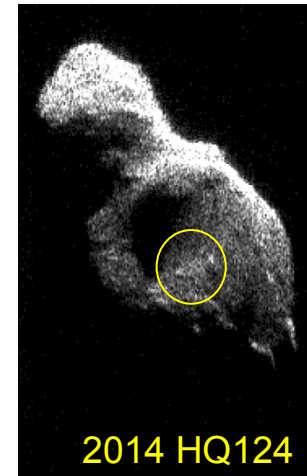
- **For Option B:**

- Lots of potential candidates
- Currently, 3 **validated** candidates:
 - **Itokawa** - imaged by Hayabusa
 - **Bennu** and **2008 EV5** – imaged by radar
- 1 possible valid candidate in 2018: **1999 JU3** - Hayabusa 2 target
- Potentially future valid candidates with inferred boulders, rate of ~1 per year

Radar Characterization of Boulders on Asteroids



- Radar cannot detect individual $<4\text{m}$ boulders, but if the SNR is high enough, $\sim 10\text{m}$ -scale features can be seen, and the presence of $<4\text{m}$ boulders can be inferred
- Radar observed $\sim 10\text{m}$ -scale features interpreted as boulders on 2014 HQ124 and 2005 YU55, but neither is in an accessible orbit
- $\sim 15\text{m}$ -scale boulders are observed on 2 candidates: Bennu & 2008 EV5 (both C-types); we infer the presence of $<4\text{m}$ boulders on these two asteroids



**Bennu and 2008 EV5 are considered
Valid Candidates for Option B
because of the
inferred presence of boulders**